Brooks, London International College; silver medal, Chas. Th. Knaus, Dulwich College.

THE *Willem Barents*, the little Polar ship which has already made three voyages to the Northern Polar Sea, has left Amsterdam for the fourth time. The crew consists of a lieutenant of the Royal Navy, H. van Broekhuyzen, as captain, two other officers, a physician, a zoologist, a photographer (the Englishman, Mr. Grant), and six sailors.

DOCTORS ARTHUR AND AUREL KRAUSE have left Bremen to spend some time in the neighbourhood of Behring Straits for the purpose of exploring and collecting, at the expense of the Bremen Geographical Society. They will visit the Chukchi peninsula, Behring Islands, and Alaska, where they will make zoological collections and carry on various scientific observations.

MR. HENRY SOLTAU and Mr. J. W. Stevenson, of the China Inland Mission, have successfully made the journey from Bhamo into China, reaching I-chan-fu, on the Yang-tsze-kiang, on March 14. This is the first time that it has been accomplished by Europeans, and the time occupied was about four months.

THE first paper in the May number of *Petermann's Mittheilungen* is a study of the Padolian Dniester region by Ritter v. Habdank Dumkowski. This is followed by the continuation of Dr. Radde's account of his journey to Talysh, Aderbeijan and the Sawalan; M. Charnay's expedition to Central America from the *North American Review*; M. Potanin's researches in Western Mongolia in 1876-77, with a map; Recent Surveys in the Western United States, with a map; and the usual Monthly Notes. Among the latter is a long account of Dr. Lenz's journey to Timbuctoo, with a sketch-map.

WE have received Nos. 1 and 3 of the *Bulletin* of the American Geographical Society, the two most important papers in which are on the recent investigations of the Gulf Stream, by the U.S. Coast Survey steamer *Blake*, by Commander J. R. Bartlett, and Changes in the Physical Geography of the Ancient Home of Man in Central and Western Asia, by the Rev. Owen Street.

DR. MOFFAT, the venerable missionary and pioneer explorer in Africa, was entertained at a banquet in the Mansion House on Saturday.

THE *Bulletin* of the Society of Commercial Geography of Bordeaux contains a brief statement of M. Paul Soleillet's views on the African question. After addressing the Society M. Soleillet proceeded to Paris, but he entertains hopes of being able to return to West Africa in November.

THE PRODUCTION OF SOUND BY RADIANT ENERGY[1]

IN my Boston paper on the photophone (NATURE, vol. xxii. p. 500) the discovery was announced that thin disks of very many different substances *emitted sounds* when exposed to the action of a rapidly-interrupted beam of sunlight. The great variety of material used in these experiments led me to believe that sonorousness under such circumstances would be found to be a general property of all matter.

At that time we had failed to obtain audible effects from masses of the various substances which became sonorous in the condition of thin diaphragms, but this failure was explained upon the supposition that the molecular disturbance produced by the light was chiefly a surface action, and that under the circumstances of the experiments the vibration had to be transmitted through the mass of the substance in order to affect the ear. It was therefore supposed that if we could lead to the ear air that was directly in contact with the illuminated surface, louder sounds might be obtained, and solid masses be found to be as sonorous as thin diaphragms. The first experiments made to verify this hypothesis pointed towards success. A beam of sunlight was focussed into one end of an open tube, the ear being placed at the other end. Upon interrupting the beam, a clear musical tone was heard, the pitch of which depended upon the frequency of the interruption of the light and the loudness upon the material composing the tube.

While in Paris a new form of the experiment occurred to my mind, which would not only enable us to investigate the sounds produced by masses, but would also permit us to test the more general proposition that sonorousness, under the influence of intermittent light, is a property common to all matter. The substance to be tested was to be placed in the interior of a transparent vessel made of some material which (like glass) is transparent to light but practically opaque to sound.

Under such circumstances the light could get in, but the sound produced by the vibration of the substance could not get out. The audible effects could be studied by placing the ear in communication with the interior of the vessel by means of a hearing tube.

Some preliminary experiments were made in Paris to test this idea, and the results were so promising that they were communicated to the French Academy on October 11, 1880, in a note read for me by Mr. Antoine Breguet.

I wrote to Mr. Tainter suggesting certain experiments, and upon my return to Washington in the early part of January, Mr. Tainter communicated to me the results of the experiments he had made in my laboratory during my absence in Europe. He had commenced by examining the sonorous properties of a vast number of substances inclosed in test-tubes in a simple empirical search for loud effects. He was thus led gradually to the discovery that cotton-wool, worsted, silk, and fibrous materials generally, produced much louder sounds than hard rigid bodies like crystals, or diaphragms such as we had hitherto used.

In order to study the effects under better circumstances he inclosed his materials in a conical cavity in a piece of brass closed by a flat plate of glass. A brass tube leading into the cavity served for connection with the hearing-tube. When this conical cavity was stuffed with worsted or other fibrous materials the sounds produced were much louder than when a test-tube was employed. Mr. Tainter next collected silks and worsteds of different colours, and speedily found that the darkest shades produced the best effects. Black worsted especially gave an extremely loud sound.

About a teaspoonful of lamp-black was placed in a test-tube and exposed to an intermittent beam of sun-light. The sound produced was much louder than any heard before. Upon smoking a piece of plate-glass, and holding it in the intermittent beam with the lamp-black surface towards the sun, the sound produced was loud enough to be heard, with attention, in any part of the room. With the lamp-black surface turned from the sun the sound was much feebler.

Upon smoking the interior of the conical cavity and then exposing it to the intermittent beam with the glass lid in position as shown, the effect was perfectly startling. The sound was so loud as to be actually painful to an ear placed closely against the end of the hearing-tube. The sounds, however, were sensibly louder when we placed some smoked wire gauze in the receiver.

When the beam was thrown into a resonator, the interior of which had been smoked over a lamp, most curious alternations of sound and silence were observed. The interrupting disk was set rotating at a high rate of speed, and was then allowed to come gradually to rest. An extremely feeble musical tone was at first heard, which gradually fell in pitch as the rate of interruption grew less. The loudness of the sound produced varied in the most interesting manner. Minor reinforcements were constantly occurring, which became more and more marked as the true pitch of the resonator was neared. When at last the frequency of interruption corresponded to the frequency of the fundamental of the resonator, the sound produced was so loud that it might have been heard by an audience of hundreds of people.

The extremely loud sounds produced from lamp-black have enabled us to demonstrate the feasibility of using this substance in an articulating photophone in place of the electrical receiver formerly employed. Words and sentences spoken into the transmitter in a low tone of voice were audibly reproduced by the lamp-black receiver at forty metres distance.

In regard to the sensitive materials that can be employed, our experiments indicate that in the case of solids the physical condition and the colour are two conditions that markedly influence the intensity of the sonorous effects. The loudest sounds are produced from substances in a loose, porous, spongy condition, and from those that have the darkest or most absorbent colours. The materials from which the best effects have been produced are cotton-wool, worsted, fibrous materials generally, cork, sponge, platinum and other metals in a spongy condition, and lamp-black.

The loud sounds produced from such substances may perhaps be explained in the following manner:—Let us consider, for example, the case of lamp-black—a substance which becomes heated by exposure to rays of all refrangibility. I look upon a mass of this substance as a sort of sponge, with its pores filled with air instead of water. When a beam of sunlight falls upon this mass the particles of lamp-black are heated, and consequently expand, causing a contraction of the air-spaces or pores among them. Under these circumstances a pulse of air should be expelled, just as we would squeeze out water from a sponge. The force with which the air is expelled must be greatly increased by the expansion of the air itself, due to contact with the heated particles of lamp-black. When the light is cut off the converse process takes place. The lamp-black particles cool and contract, thus enlarging the air-spaces among them, and the inclosed air also becomes cool. Under these circumstances a partial vacuum should be formed among the particles, and the outside air would then be absorbed as water is by a sponge when the pressure of the hand is removed.

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[1] Abstract of a paper by Prof. Alexander Graham Bell, read before the National Academy of Arts and Sciences, April 21, 1881.

I imagine that in some such manner as this a wave of condensation is started in the atmosphere each time a beam of sunlight falls upon lamp-black, and a wave of rarefaction is originated when the light is cut off. We can thus understand how it is that a substance like lamp-black produces intense sonorous vibrations in the surrounding air, while at the same time it communicates a very feeble vibration to the diaphragm or solid bed upon which it rests.

In his paper read before the Royal Society on March 10 Mr. Preece describes experiments from which he claims to have proved that the effects are wholly due to the vibrations of the confined air, and that the disks do not vibrate at all.

But for reasons stated Mr. Bell concludes that in the case of thin disks a real vibration of the diaphragm is caused by the action of the intermittent beam, independently of any expansion and contraction of the air confined in the cavity behind the diaphragm. Lord Rayleigh has shown mathematically that a to-and-fro vibration, of sufficient amplitude to produce an audible sound, would result from a periodical communication and abstraction of heat, and he says: "We may conclude, I think, that there is at present no reason for discarding the obvious explanation that the sounds in question are due to the bending of the plates under unequal heating" (NATURE, vol. xxiii. p. 274).

[Mr. Bell then describes experiments (devised by Mr. Tainter) which have given results decidedly more favourable, in his opinion, to the theory of Lord Rayleigh than to that of Mr. Preece.]

The list of solid substances that have been submitted to experiment in my laboratory is too long to be quoted here, and I shall merely say that we have not yet found one solid body that has failed to become sonorous under proper conditions of experiment.[1]

The sounds produced by liquids are much more difficult to observe than those produced by solids. The high absorptive power possessed by most liquids would lead one to expect intense vibrations from the action of intermittent light, but the number of sonorous liquids that have so far been found is extremely limited, and the sounds produced are so feeble as to be heard only by the greatest attention and under the best circumstances of experiment. In the experiments made in my laboratory a very long test-tube was filled with the liquid under examination, and a flexible rubber-tube was slipped over the mouth far enough down to prevent the possibility of any light reaching the vapour above the surface. Precautions were also taken to prevent reflection from the bottom of the test-tube. An intermittent beam of sunlight was then focussed upon the liquid in the middle portion of the test-tube by means of a lens of large diameter.

Results

Clear water	No sound audible.
Water discoloured by ink	Feeble sound.
Mercury	No sound heard.
Sulphuric ether *	Feeble, but distinct sound.
Ammonia	,, ,,
Ammonio-sulphate of copper ...	,, ,,
Writing ink	,, ,,
Indigo in sulphuric acid	,, ,,
Chloride of copper *	,, ,,

The liquids distinguished by an asterisk gave the best sounds.

Acoustic vibrations are always much enfeebled in passing from liquids to gases, and it is probable that a form of experiment may be devised which will yield better results by communicating the vibrations of the liquid to the air through the medium of a solid rod.

The vapours of the following substances were found to be highly sonorous in the intermittent beam:—Water vapour, coal gas, sulphuric ether, alcohol, ammonia, amylene, ethyl bromide, diethylamene, mercury, iodine, and peroxide of nitrogen. The loudest sounds were obtained from iodine and peroxide of nitrogen. I have now shown that sounds are produced by the direct action of intermittent sunlight from substances in every physical condition (solid, liquid, and gaseous), and the probability is therefore very greatly increased that sonorousness under such circumstances will be found to be a universal property of matter.

At the time of my communication to the American Association the loudest effects obtained were produced by the use of selenium, arranged in a cell of suitable construction and placed in a galvanic circuit with a telephone. But the selenium was very inconstant in its action, and from experiments by Dr. Chichester Bell of University College of London, it was found that all the selenium used was tainted with impurities.

Prof. W. G. Adams (*Proceedings* Royal Society, vol. xxiv. p. 163) has shown that tellurium, like selenium, has its electrical resistance affected by light, and we have found that when this tellurium spiral is connected in circuit with a galvanic battery and telephone and exposed to the action of an intermittent beam of sunlight, a distinct musical tone is produced by the telephone.

It occurred to Mr. Tainter before my return to Washington last January that the very great molecular disturbance produced in lamp-black by the action of intermittent sunlight should produce a corresponding disturbance in an electric current passed through it, in which case lamp-black could be employed in place of selenium in an electrical receiver. This has turned out to be the case, and the importance of the discovery is very great, especially when we consider the expense of such rare substances as selenium and tellurium.

We have observed that different substances produce sounds of very different intensities under similar circumstances of experiment, and it has appeared to us that very valuable information might be obtained if we could measure the audible effects produced. For this purpose we have constructed several different forms of apparatus for studying the effects, but our researches are not yet complete. When a beam of light is brought to a focus by means of a lens the beam diverging from the focal point becomes weaker as the distance increases in a calculable degree. Hence if we can determine the distances from the focal point at which two different substances emit sounds of equal intensity we can calculate their relative sonorous powers. Preliminary experiments were made by Mr. Tainter during my absence in Europe to ascertain the distance from the focal point of a lens at which the sound produced by a substance became inaudible. A few of the results obtained will show the enormous differences existing between different substances in this respect.

Distance from Focal Point of Lens at which Sounds become Inaudible with Different Substances

		m.
Zinc diaphragm (polished)		1·51
Hard rubber diaphragm		1·90
Tin foil	,, ...	2·00
Telephone	,, (japanned iron)	2·15
Zinc	,, (unpolished)	2·15
White silk	(in receiver)	3·10
White worsted	,, ...	4·01
Yellow worsted	,, ...	4·06
Yellow silk	,, ...	4·13
White cotton-wool	,, ...	4·38
Green silk	,, ...	4·52
Blue worsted	,, ...	4·69
Purple silk	,, ...	4·82
Brown silk	,, ...	5·02
Black silk	,, ...	5·21
Red silk	,, ...	5·24
Black worsted	,, ...	6·50
Lamp-black. In receiver the limit of audibility could not be determined on account of want of space. Sound perfectly audible at a distance of		10·00

Mr. Tainter was convinced from these experiments that this field of research promised valuable results, and he at once devised an apparatus for studying the effects, which he described to me upon my return from Europe. [The apparatus has since been constructed, and Mr. Bell gave a detailed description of it.]

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[1] Carbon and thin microscope glass are mentioned in my Boston paper as non-responsive, and powdered chlorate of potash in the communication to the French Academy (*Comptes rendus*, vol. xcl., p. 595) All these substances have since yielded sounds under more careful conditions of experiment.

The meaning we have uniformly attached to the words "photophone" and "light" will be obvious from the following passage quoted from my Boston paper :—

"Although effects are produced as above shown by forms of radiant energy, which are invisible, we have named the apparatus for the production and reproduction of sound in this way the 'photophone,' because an ordinary beam of light contains the rays which are operative."

To avoid in future any misunderstandings upon this point we have decided to adopt the term "*radiophone*" proposed by M. Mercadier as a general term signifying an apparatus for the production of sound by any form of radiant energy, limiting the words *thermophone*, *photophone*, and *actinophone* to apparatus for the production of sound by thermal, luminous, or actinic rays respectively. M. Mercadier, in the course of his researches in radiophony, passed an intermittent beam from an electric lamp through a prism, and then examined the audible effects produced in different parts of the spectrum (*Comptes rendus*, December 6, 1880). We have repeated this experiment, using the sun as our source of radiation, and have obtained results somewhat different from those noted by M. Mercadier. A beam of sunlight was reflected from a heliostat through an achromatic lens, so as to form an image of the sun upon the slit. The beam then passed through another achromatic lens and through a bisulphide of carbon prism, forming a spectrum of great intensity, which, when focussed upon a screen, was found to be sufficiently pure to show the principal absorption lines of the solar spectrum. The disk-interrupter was then turned with sufficient rapidity to produce from five to six hundred interruptions of the light per second, and the spectrum was explored with the receiver, which was so arranged that the lamp-black surface exposed was limited by a slit, as shown.

Under these circumstances sounds were obtained in every part of the visible spectrum, excepting the extreme half of the violet, as well as in the ultra-red. A continuous increase in the loudness of the sound was observed upon moving the receiver gradually from the violet into the ultra-red. The point of maximum sound lay very far out in the ultra-red. Beyond this point the sound began to decrease, and then stopped so suddenly that a very slight motion of the receiver made all the difference between almost maximum sound and complete silence.

2. The lamp-blacked wire gauze was then removed and the interior of the receiver was filled with red worsted. Upon exploring the spectrum as before, entirely different results were obtained. The maximum effect was produced in the green at that part where the red worsted appeared to be black. On either side of this point the sound gradually died away, becoming inaudible on the one side in the middle of the indigo, and on the other at a short distance outside the edge of the red.

3. Upon substituting green silk for red worsted the limits of audition appeared to be the middle of the blue and a point a short distance out in the ultra-red. Maximum in the red.

4. Some hard-rubber shavings were now placed in the receiver. The limits of audibility appeared to be on the one hand the junction of the green and blue, and on the other the outside edge of the red. Maximum in the yellow. Mr. Tainter thought he could hear a little way into the ultra-red, and to his ear the maximum was about the junction of the red and orange.

5. A test-tube containing the vapour of sulphuric ether was then substituted for the receiver. Commencing at the violet end, the test-tube was gradually moved down the spectrum and out into the ultra-red without audible effect, but when a certain point far out in the ultra-red was reached a distinct musical tone suddenly made its appearance, which disappeared as suddenly on moving the test-tube a very little further on.

6. Upon exploring the spectrum with a test-tube containing the vapour of iodine the limits of audibility appeared to be the middle of the red and the junction of the blue and indigo. Maximum in the green.

7. A test-tube containing peroxide of nitrogen was substituted for that containing iodine. Distinct sounds were obtained in all parts of the visible spectrum, but no sounds were observed in the ultra-red.

The maximum effect seemed to me to be in the blue. The sounds were well-marked in all parts of the violet, and I even fancied that the audible effect extended a little way into the ultra-violet, but of this I cannot be certain. Upon examining the absorption-spectrum of peroxide of nitrogen it was at once observed that the maximum sound was produced in that part of the spectrum where the greatest number of absorption lines made their appearance.

8. The spectrum was now explored by a selenium cell, and the audible effects were observed by means of a telephone in the same galvanic circuit with the cell. The maximum effect was produced in the red. The audible effect extended a little way into the ultra-red on the one hand and up as high as the middle of the violet on the other.

Although the experiments so far made can only be considered as preliminary to others of a more refined nature, I think we are warranted in concluding that the nature of the rays that produce sonorous effects in different substances depends upon the nature of the substances that are exposed to the beam, and that the sounds are in every case due to those rays of the spectrum that are absorbed by the body.

Our experiments upon the range of audibility of different substances in the spectrum have led us to the construction of a new instrument for use in spectrum analysis. The eye-piece of a spectroscope is removed, and sensitive substances are placed in the focal point of the instrument behind an opaque diaphragm containing a slit. These substances are put in communication with the ear by means of a hearing-tube, and thus the instrument is converted into a veritable "spectrophone."

Suppose we smoke the interior of our spectrophonic receiver, and fill the cavity with peroxide of nitrogen gas. We have then a combination that gives us good sounds in all parts of the spectrum (visible and invisible) except the ultra violet. Now pass a rapidly-interrupted beam of light through some substance whose absorption spectrum is to be investigated, and bands of sound and silence are observed upon exploring the spectrum, the silent positions corresponding to the absorption bands. Of course the ear cannot for one moment compete with the eye in the examination of the visible part of the spectrum ; but in the invisible part beyond the red, where the eye is useless, the ear is invaluable. In working in this region of the spectrum lamp-black alone may be used in the spectrophonic receiver. Indeed the sounds produced by this substance in the ultra-red are so well marked as to constitute our instrument a most reliable and convenient substitute for the thermo-pile. A few experiments that have been made may be interesting.

1. The interrupted beam was filtered through a saturated solution of alum.

Result : The range of audibility in the ultra-red was slightly reduced by the absorption of a narrow band of the rays of lowest refrangibility. The sounds in the visible part of the spectrum seemed to be unaffected.

2. A thin sheet of hard rubber was interposed in the path of the beam.

Result : Well-marked sounds in every part of the ultra-red. No sounds in the visible part of the spectrum, excepting the extreme half of the red.

These experiments reveal the cause of the curious fact alluded to in my paper read before the American Association last August—that sounds were heard from selenium when the beam was filtered through both hard rubber and alum at the same time.

3. A solution of ammonia-sulphate of copper was tried.

Result : When placed in the path of the beam the spectrum disappeared, with the exception of the blue and violet end. To the eye the spectrum was thus reduced to a single broad band of blue-violet light. To the ear however the spectrum revealed itself as two bands of sound with a broad space of silence between. The invisible rays transmitted constituted a narrow band just outside the red.

I think I have said enough to convince you of the value of this new method of examination, but I do not wish you to understand that we look upon our results as by any means complete. It is often more interesting to observe the first totterings of a child than to watch the firm tread of a full-grown man, and I feel that our first footsteps in this new field of science may have more of interest to you than the fuller results of mature research. This must be my excuse for having dwelt so long upon the details of incomplete experiments.

I recognise the fact that the spectrophone must ever remain a mere adjunct to the spectroscope, but I anticipate that it has a wide and independent field of usefulness in the investigation of absorption spectra in the ultra-red.